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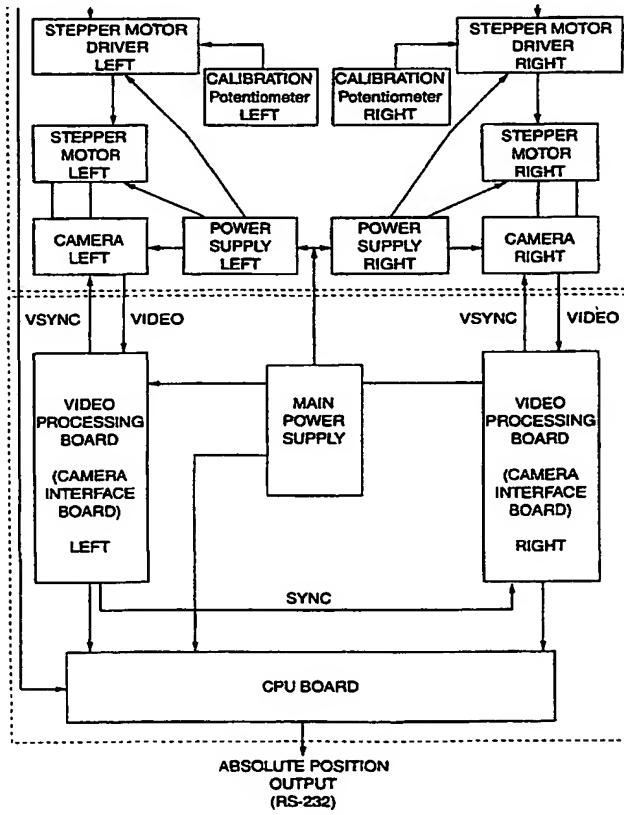
## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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**(54) Title: EYE TRACKING APPARATUS****(57) Abstract**

The present invention relates to a tracking system for locating the eyes of a viewer including: an illumination means (61); a plurality of cameras (60); and a processing means (55); wherein at least the viewer's eyes are illuminated by the illumination means (61) to enable capture by each camera (60), and wherein the processing means (55) is adapted to process images from each camera (60) so as to detect the position of the viewer's eyes.



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## EYE TRACKING APPARATUS

### Field of the Invention

The Present invention is directed towards an improved eye tracking apparatus, and in particular an eye tracking apparatus for use on an auto stereoscopic viewing system.

### Background Art

The present Applicant's original 3-D auto stereoscopic display unit included an eye tracking unit to enable the correct positioning of a stereoscopic projector pair, to thereby enable the observer to view 3-D video without the use of special glasses. This tracking system, which was disclosed in Australian Application No. 42929/96, required the data for the location of eyes in the x and y directions. That is, the horizontal and the vertical positions of the eyes from a known datum point at a set distance from the single camera.

The earlier developments were based on the premise that the viewer would be located a relatively fixed distance from the screen. However, it is now desirable to develop a system which is able to determine the location of the eyes in the x, y and z directions. That is, the horizontal (lateral) position, vertical (height) position and horizontal (depth) position from a known datum point.

Such a system will enable an observer to move left and right, up and down, and also forwards and backwards with respect to the screen. However, to create such a system additional data is required in order to obtain the depth or z information.

The present applicants have investigated a number of alternative systems using feed back focus information and ultrasonics. However these other methods have not been found to be technically or commercially practical at this time.

### Objects of the Invention

It is therefore the object of the present invention to provide an eye tracking system which is capable of providing the location of the observer's eyes in the x, y and z directions.

It is also intended that the observer should not be required to wear any specific head-gear and the system should track the observer reliably

irrespective of any corrective glasses worn by the observer. Preferably, the system should correctly report the observers eye position during momentary blinking or periods where one or both of the observers eyes are closed or the viewer has momentarily looked away from the system. Ideally, it is also 5 intended that the system should reliably differentiate between the observers eyes and other facial features e.g. earrings or background objects.

#### Summary of the Invention

With the above object in mind the present invention provides in one aspect a tracking system for locating the head and/or eyes of a viewer including 10 an illumination means; a plurality of cameras; and a processing means; wherein at least one of the viewer's eyes is illuminated by the illumination means to enable capture by each camera, and said processing means is adapted to process images from each camera so as to detect the position of the viewer's eyes and/or head.

15 For a system that is required to track in the z direction as well as x and y then preferably two cameras can be located on either side of the observers head or the autostereoscopic display system that requires the coordinates of the observer to be determined. The processing means is then able to utilise a method of triangulation to locate the viewer's head and/or eyes. In order to 20 obtain a more compact tracking system, each camera can be associated with a corresponding mirror ideally located at 135° relative to the optical axis of each respective camera. The addition of such mirrors do not adversely affect the performance of each camera, but do allow for a more compact system.

Ideally, the illumination means can be formed from a plurality of separate 25 illumination means, each separate illumination means being moveable in response to movement of the viewer.

It will be understood that such illumination means will conform with local safety regulations.

In a further aspect the present invention provides a tracking tower for 30 locating the eyes of a viewer including:

an illumination means for illuminating at least the eyes of a viewer;  
a vertically mounted camera for capturing at least the reflected light from

the eyes of the viewer; and

a mirror positioned to enable the vertically mounted camera to capture images in front of the tracking tower.

In yet a further aspect the present invention provides a method of tracking

5 the eyes of a viewer including:

projecting light capable of being reflected from the cornea of a viewer from an illumination means onto the eyes of the viewer;

capturing the image of the viewer by a plurality of cameras capable of detecting the reflected light from the viewers cornea;

10 and processing the captured images from each camera in a processing means to determine the position of the viewers eyes.

In another aspect the present invention provides an autostereoscopic display system including:

a display means for displaying images to be viewed by a viewer;

15 a tracking tower located on either side of the display means, each tracking tower including:

an upper and lower illumination means for illuminating at least the eyes of a viewer;

20 a vertically mounted camera for capturing at least the reflected light from the eyes of the viewer; and

a mirror positioned to enable the vertically mounted camera to capture images of the viewer in front of the tracking tower;

25 a processing means located below the display means for receiving the images captured by each camera, determining the position of the viewers eyes, and sending the output from the processing means to each tracking tower to thereby adjust each said camera in response to movement of the viewer;

and wherein the output from the processing means is utilised to display respective left and right eye images of the image to be viewed by the viewer on the display means.

30 Brief description of drawings

Figure 1 shows a preferred set-out of the present invention.

Figure 2 shows an example of a tracking tower which corresponds to one

embodiment of the present invention.

Figure 3 shows a block diagram of the typical elements of the tracking towers (minus illuminating means) and processing means of one embodiment of the present invention.

5 Figure 4a-c show a flow diagram of the calibration system of one embodiment of the present invention.

Figure 5a-b, show a flow diagram of the operation of the eye tracker and the head tracker in the preferred embodiment.

10 Figure 6 shows a block diagram of hardware requirements for one embodiment of the present invention.

#### Detailed Description

In order that the system should reliably track the eyes of an observer, under standard domestic and industrial ambient lighting conditions, it was necessary to determine the optimum manner in which the observers face should 15 be illuminated so as to maximize the uniqueness of the reflections from the observers eyes and minimize the occurrence of other reflections that could be mistaken as eye reflections.

Through experimentation it was discovered that a localized source of light shone into the face of an observer returned a high level of reflection of that 20 source from the cornea of the observers eyes. In viewing these cornea reflections it was observed that the characteristics of such reflections were sufficiently unique to enable them to be reliably differentiated from other reflections from the observers face, and also other objects within the vicinity of the observer.

25 In order to prevent discomfort to the viewer, a source of non-visible light is desirable and infrared is a preferred solution.

However, should the observer be wearing corrective glasses, it was determined that reflections from the cornea may not be detectable through the 30 glasses, or may be difficult to differentiate from reflections of the illuminating light source from the observers glasses.

Under these circumstances, it was noted that the reflections from the outside rim of the glasses were sufficiently unique to enable them to be reliably

differentiated from other reflections from the observers face and other objects within the vicinity of the observer.

Since the general shape of glasses are well known, it is possible to determine the left, right, upper and lower boundaries of the observers glasses  
5 and from this rectangle estimate the x and y coordinates of the observers eye(s).

If the x and y coordinates of the observers eyes or glass rims, in relation to some fixed datum, are to be located then illuminating the observers face with a localized source of infrared light and imaging the viewers face with a video camera sensitive to infrared light will enable the use of computer image  
10 processing techniques to determine these coordinates. This is a preferred embodiment of the current invention.

Since general eye and glasses characteristics are generally consistent between observers, computer image processing techniques can take advantage of these characteristics and use them to distinguish between wanted and  
15 unwanted reflections.

Should the distance z of the observer from a fixed datum also be required then two such configurations can be placed a known distance apart, and in the preferred embodiment, either side of the viewers face or autostereoscopic display device, and standard triangulation techniques applied to determine the z  
20 distance of the observer from the datum.

This configuration will enable the eyes or glasses of the observer to be tracked within a volume determined by the characteristics of the lens of the video camera used. Whilst a wide angle lens could be used to provide a large tracking area this will also image objects other then the observers face which  
25 could result in extraneous objects being incorrectly interpreted as eyes, thus reducing the reliability of the tracking system.

In order to increase the reliability of eye tracking it is desirable that the video camera should utilise a narrow angle lens, such that only the observers eyes are imaged and other extraneous objects are eliminated.

30 However, such a configuration may yield an unacceptably small volume within which the observers eyes can be successfully tracked .

In order to increase the tracking volume, without reducing the reliability of

the system, the video camera(s) can pan and tilt so as to follow the observers movements. This can be achieved since, once the initial location of the observers eyes have been determined, the x and y coordinates so obtained can be used as the input of a pan and tilt control system that keeps the observers 5 eyes within the field of view of the video camera(s). Should the location of the viewers eyes be lost then after a predetermined period the control system would return the camera to a known home position.

Additionally, once the viewers eyes have been located the characteristics of the lens of the video camera can be altered, by the use of a power zoom for 10 example, to optimise the image size as the position of the observer changes in the z axis.

In more detail, the preferred embodiment of the present invention involves the use of two horizontally mounted cameras fitted with power pan, tilt, zoom and focus. Alternatively, for functional compactness the cameras can be 15 mounted vertically and use a mirror oriented at 45° to the horizontal, to obtain the correct field of view. It will be appreciated that a camera would normally be horizontally mounted. If space constraints require the camera to be mounted vertically, the mirror will be required to correct the optical path of the camera. Further, the camera need not be vertically mounted at 90°, but rather may be at 20 any angle convenient to the particular application provided that the orientation of the mirror is adjusted to provide the correct optical path for the camera. This mirror may be fixed, therefore giving no tilt function or, articulated to achieve the tilt function. The independent data derived from both cameras can be processed through triangulation to find the x, y and z depth data.

25 Preferably, the illumination means includes infra red (IR). In order that the system will operate within the safety requirements for IR illumination, a camera with high sensitivity in the IR region is required. The functional requirement of the camera is to capture the reflected light from the viewer's cornea, or rim of corrective glasses if worn. Ideally the reflected IR light is captured over two or 30 three pixels of the camera's CCD element. This interpolates to the camera's field of view, at the greater viewing range, to span approximately 1½ head widths. The three dimensional space detailed by x, y and z as a region in which

eye tracking is effective, will be referred to as the zone of regard. In order to achieve the inspection of, or to scan the zone of regard, the camera needs to pan horizontally.

As previously indicated the safe usage of the equipment is a primary 5 design requirement in order to conform to respective IR safety regulations. For example, in Australia the IR illumination level must be below the Class 1 IR Illumination Standards Requirement. This IR illumination level must also be safe for the casual observer and not only the primary viewer. That is, the IR illumination level must be safe for both the primary viewer, and also for any 10 person who may come within the illuminated region. In order to further reduce the mean level of IR the observer, or other person in the vicinity of the system, is exposed to, the IR illumination source may be pulsed rather than permanently illuminated. In the preferred embodiment the IR source would be turned on for a period during which the shutter of the CCD video camera is open.

15 As a further means of reducing the level of IR radiation the observer is exposed to, the on time of the illumination source can be varied. Since the distance of the observer from the system is known, the length of time the IR illumination is on can be altered in relation to the distance the viewer is from the IR source. Since less illumination is required the closer the observer is to the 20 illumination source, as the observer moves closer to the system the on time can be reduced and visa versa.

Should the shutter speed of the CCD camera be altered in accordance with the distance of the observer from the camera, or other parameters, then the on time of the IR source may be varied accordingly.

25 Preferably, the cameras are equipped with a pan mechanism in order to increase the horizontal field of view of the eye tracker system. Accordingly, in order to accommodate the pan movement requirement, the illumination means (61a and 61b) is ideally coaxially articulated in the direction of the camera so as to further assist in minimising illumination energy and satisfying IR illumination 30 Safety Standards. It will be understood that the illumination means need not be formed by an upper and lower illumination means, but could be formed by a single illumination means, or other functionally equivalent arrangement. In

another preferred embodiment the illumination sources are located close to the viewers face, in order to maximise the incident IR radiation on the face of the observer, and the cameras located some distance behind.

As can be seen from Figures 1 and 2, in a preferred embodiment the 5 present invention provides two tracking towers (54), one either side of the screen (70) and a processing means (55) located below the screen (70) in a base unit (72). The tracking towers (54) may be inclined towards the centre of the screen (70) to ensure the area in front of the screen (70) is illuminated. Ideally, this angle of inclination is approximately 20°. Preferably, each tracking 10 tower (54) contains a panning camera (60) for tracking the viewer's eyes. Such a Dual Pan Eye Tracking Apparatus may conveniently consist of two tracking towers (54) and a processor module (55). The tracking towers (54) can include a support frame (73), and an IR illumination carrier frame (74) with mounts and pivots. In the preferred embodiment, each tracking tower includes an upper 15 illumination means (61a) and a lower illumination means (61b). Both the upper and lower illumination means (61a, 61b) may be formed by a bank of infra-red LED's all of which act to illuminate the viewer. Ideally, the, or each, illumination means is moveable and also generally tracks the viewer's head. The orientation of the illumination means (61) can be arranged as a result of 20 feedback from the processing means (55). That is, the processing means (55) can be used to locate the viewer's eyes for an autostereoscopic display device, and also for adjustments to the illumination means (61) which assisted in the location of the viewer's eyes. This movement of the illumination means (61) has the advantage that sufficient light illuminates the viewer at all times thereby 25 enabling the cameras (60) and processing means (55) to detect the viewer's eyes and/or head. Further, the use of directional illuminating means improves the ability of the system to meet IR safety regulations. A stronger, more focussed, "beam" may be directed at the viewer, without the need to flood the entire area in infra-red. A feature which may be of particular relevance to any 30 casual observers.

The towers (54) may also include a stepper motor or DC motor (56), a mirror (57), a position feed back device (58), that measures the angle through

which the tower rotates and a power supply (59). This preferred layout is shown at Figure 2. This shows a vertical axis pan unit with a front silvered mirror (57) at 45°. The inclusion of a mirror (57) in the tracking towers (54) allows for a more compact unit, which would be less obtrusive to the viewer, and require less real estate. The mirror (57) can be fixed with respect to the camera (60) or moveable. A fixed mirror decreases the amount of processing power required to determine the position of the viewer's eyes. However, a moveable mirror has the advantage of increasing the degree of freedom afforded to the viewer's movement. That is, a moveable mirror will enable a viewer to be tracked over a greater area than a fixed mirror.

The IR Tracking Camera (60) can be mounted so the axis of the stepper motor (56) is in the optical centre of the camera lens, i.e. the camera is arranged to pivot about its optical centre. The camera (60) revolves with the mirror unit (57) and remains in a relative axial position to the illumination arrays (61a, 61b). Aligning adjustments can be incorporated in the design to allow for initial set up and calibration adjustments. As an alternate to the stepper motor (56), a DC servomotor with a PID controller could provide the rotation drive for the camera and IR illumination arrays.

The processor unit (55) may consist of a Composite Video Image Processor for each camera (60) and a CPU Board. The processing of the video signal is ideally undertaken in hardware and software. Positional information of the eye location is constantly calculated in the CPU and the information used to drive the stepper motor (56) and hence the camera pan mechanism. The absolute position information of the centre of reference between the eyes (as x, y and z coordinates) is also supplied as an output.

The processor unit (55) locates the position of the eyes by examining the video image. The processor examines the image from the video camera to determine the areas of the image that have high brightness levels. Since the viewer's face is being illuminated with infrared light, then one of the highest levels of natural reflections or brightness levels from the face will be the reflection of the infrared light source from the cornea of the viewer's eyes. The processor searches for these reflections on the basis that there are two eyes,

that they are approximately 67mm apart, and that they are located approximately horizontal to one another. After the eyes have been located initially, these attributes are used to verify that the bright features identified are in fact eyes and not other similar objects within the image.

5 There are two calibration sequences for this preferred embodiment. The first is a full set up calibration. The Flow Diagram of Figure 4(a-c) details one embodiment of the calibration of the complete unit. A calibration frame is positioned in front of the complete unit. This frame consists of a series of IR LED's (the absolute position of each LED is known) on a horizontal and vertical 10 axis, in the preferred embodiment the LED's are configured in the form of a cross. The z distance from the calibrations frame's LED's to the prescribed calibration datum point is also known. The operation of the LED's are controlled 15 from the processor unit (55).

Figure 4(a-c) details the operation of the calibration for this preferred 20 embodiment. The calibration frame is mounted (1) at the calibration height and distance from the tracking towers (54). The calibration frame is powered up (2) by plugging into the processor unit (55) via a cable. Data is supplied via a monitor port on the processor unit (55). The first part of the calibration involves 25 the alignment of the tracking towers (54), accordingly the tower alignment test (3) is initiated. The routine for adjusting the alignment of tower 1 is undertaken (4, 5 and 6) automatically on power up. This consists of moving the tower alignment until a nulled result is obtained. A similar routing is undertaken on tower 2, (7, 8 and 9) again until a nulled result is obtained. This completes the alignment calibration. Note: Figures 1 and 2 do not show alignment 30 mechanism.

The next step is the camera roll adjustment. Roll adjustment compensates for the fact that the CCD element within the camera may not be mounted exactly horizontal within the camera mounting and compensates for the fact that in the preferred embodiment the camera is mounted pointing 35 inwards and upwards towards the observer. Camera roll test is initiated (10) automatically on successful completion of the tower alignment routines. The routine for the rotational or roll alignment of camera 1 is undertaken (11, 12 and

13). This consists of rotating the camera in its mounting until a nulled result is obtained. A similar routine is undertaken on camera 2 (14, 15 and 16) again until a nulled result is obtained.

The next stage, horizontal calibration (17) is automatically initiated on 5 successful completion of the camera roll calibration. This calibration routine is also an automatic process. The iterative routine (18, 19, 20 and 21) is performed on data processed from the two cameras. The calculated x, y and z position of each of the horizontal calibration LED's is stored. The absolute positions of the horizontal LED's are then used to calculate (22) the horizontal 10 calibration constants for the system.

Vertical calibration (23) is carried out in a similar manner to the horizontal calibration (17). The iterative routine (24, 25, 26 and 27) is performed on data processed from the two cameras. The calculated x, y and z position of each of the vertical calibration LED's is stored. The absolute position of the vertical 15 LED's are then used to calculate (28) the vertical calibration constants for the system.

The final calibration step is to store the calibration constants in non-volatile memory (29).

The second calibration phase is an ongoing operational check 20 calibration. This is related to the stepper motor drive system, where the step count is checked against the positional feed back device and corrected as required. This could be undertaken automatically with a DC servo motor with a PID control.

In an alternative embodiment, the illumination means is separated from 25 the camera, in that they need not be located in the same tracking tower. This enables the illumination source to be located closer to the viewers face, thereby enabling the illumination means to have lower power usage, and reduced beam width, features which in an infra red environment assist in the system meeting the necessary health and safety standards. This embodiment also allows the 30 camera(s) to be located further away from the viewer, and out of sight of the viewer if desired. Such cameras are also more likely to be able to employ a standard angle lens, as opposed to the likelihood of requiring cameras with

wide angle lens, as the camera need not be located close to the viewer and illumination source.

The present invention may also be adapted to address one of the major problems associated with attempts to perform eye tracking, in the temporary loss 5 of eye reflections associated with either blinking or looking away in another direction. To address this problem at least one further reference point for the eyes can be incorporated. This further reference point should only be achieved after eye lock (valid eye recognition) is confirmed. The method may be called associated head tracking and involves additional software routines. After the 10 valid eye recognition is achieved, the system looks above the position of the eyes to find the edges of the head approximately in the position of the forehead. This is a transient point between the darkness of the background and the lighter face. One point either side of the face can be established and the eye positions referenced to these points. If the eye lock is momentarily lost, the system can 15 then continue to calculate the position of the eyes based on these reference point. Ideally, the position reference can be continually updated while eye lock is established if required.

Figures 5a and 5b detail the operation of the eye tracking with head tracking system for this preferred embodiment of the invention. The system is 20 initialised (30) automatically on power up. The operation of the system can be considered to be a continuous process to output a constant data stream for the absolute x, y and z positions of the observer's eyes. This is obtained by reading the eye reflection data from camera 1 (31) and reading the head tracking data from camera 1 (32). The eye reflection data is compared with the known 25 characteristics of a valid eye reflection, in terms of shape and size etc, that are stored as parameters within the program. If the comparison does not indicate that a valid eye reflection has been located then the camera is panned to the home position after a predetermined time out period. Once a valid set of eye reflections have been established a referenced head position can be indexed to 30 the eye position and will be retained as a valid head position (34). If subsequent valid eye data is not returned, due to blinking or closing the eyes, the head position is then used to calculate the eye position (35). If the valid eye

position indicates the observer is near the horizontal limit of the field of view of the camera the stepper motor will be instructed to pan the camera (37) to centralise the image in the field of view. Whilst the embodiment described is predominately intended to track an observer as they move in the x axis, should 5 the valid eye position indicate that the observer is near the vertical limit of the field of view then a tilt mechanism attached to the camera, or 45 degree mirror, would enable the tracking in this direction to also be extended.

The same process is used for camera 2 (39 to 46) as described for camera 1 (31 to 38). With valid and or calculated eye reflections from both 10 cameras (47) the eye position in x, y and z can be calculated (48). If valid or calculated eye reflections are not available then no valid output can be calculated and the previous values for x, y and z are repeated until valid data updates the system. An invalid data counter (62) is in both the camera 1 and the camera 2 flow diagram. If the camera data continues to register invalid, the 15 camera will pan to the home position.

Such a system can also be adapted to establish a stable position indication of the eyes even when the viewer is wearing glasses. The reflections from glasses are multiple and can be fast moving and unstable. Once the position of the glasses is established, the system looks for the transient from the 20 dark background to the lighter face above the level of the glasses. As the viewer moves, looks down or right and left the reference points act as a filter, rejecting the invalid data and updating the reference when valid position data is processed.

The confinement of IR light to below the level of Class 1 IR Illumination 25 Standards Requirement was considered a design criteria. Two methods were formulated to ensure the present invention provides a safe working environment. The first involved determining the minimum IR Illumination possible to obtain accurate and repeatable eye position data. This involved the incorporation of a low light (IR) camera together with the axial mounted IR 30 Illumination. The stand by condition of the system assumes that the viewer will enter the home position in the first third of the z viewing distance. The IR illumination and shutter speed is optimised for this viewing distance. As the

viewer moves back (increase in z) the shutter speed is dynamically decreased and the IR illumination time is increased. The second method involves viewers not being the primary viewer. With the IR illumination articulated coaxially with the camera and with the IR LED's having an emission cone of a 40° solid angle, 5 any other observer is outside the influence of the IR illumination and therefore exposed to less than Class 1 IR illumination Standards.

The cameras are also synchronised to minimise the IR illumination on time and to improve the accuracy of the system.

Figure 6 details a typical block diagram of the hardware aspects of the 10 operation for this preferred embodiment. Video from the camera(s) is converted from an analog to a digital signal (49). Hardware processes the digital data using transient reflection detection (50) and threshold detection (51) to obtain the x and y positions of the reflections and the x positions of the left and right edges of the observer's head (above the level of the detected eyes). High level 15 filtering is used to establish the X and y position of the detected reflections with respect to the camera's field of view (52). The x and y rectangular position are then converted to a polar coordinate position (53). That is the x and y position with respect to the camera field of view is converted to the horizontal and vertical components of angle to the eye position with respect to the optical axis of the 20 camera. With this positional data from both cameras and the positional data from the pan position of the cameras the absolute location of the eyes in x, y and z space can be calculated. This data can be output from the system via a nominated data stream format in various serial communication modes or other methods familiar to those skilled in the art.

25 The present invention is of particular advantage to the Applicant's existing autostereoscopic display system, however, it is also of advantage to all other autostereoscopic display systems. The tracking system as disclosed herein allows the viewer additional freedom of movement not available in existing systems. Where previously the viewer was constrained to remain a 30 relatively fixed distance from the display means, the present invention provides a system whereby the viewer can move away from, or towards, the screen without loss of stereoscopic effect. That is, the ability to track the viewer's eyes

in the x, y and z directions enables the stereoscopic system to correctly project the left eye and right eye images for viewing by the viewer's respective left and right eyes.

Whilst the main advantage of the eye tracking unit of the present invention is that the viewer is not required to remain a fixed distance from the screen, the preferred embodiments of the present invention are also able to address other problems with existing systems which attempt to track a viewer's eyes in the x and y direction by being able to compensate for when valid eye data is not valid, or the viewer is wearing glasses. However, it will be understood that modifications and variations such as would be apparent to a skilled addressee are considered within the scope of the present invention.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A tracking system for locating the eyes of a viewer including:
  - an illumination means;
  - a plurality of cameras; and
  - a processing means;wherein at least the viewer's eyes are illuminated by the illumination means to enable capture by each camera, and wherein said processing means is adapted to process images from each camera so as to detect the position of the viewer's eyes.
2. A tracking system as claimed in claim 1 wherein at least one of said cameras is located on either side of a display means for displaying images to be viewed by the viewer.
3. A tracking system as claimed in claim 1 or claim 2 wherein the processing means utilises a method of triangulation to assist in the location of the viewer's eyes.
4. A tracking system as claimed in any preceding claim wherein said at least one camera is mounted vertically and wherein the, or each, vertically mounted camera is associated with a mirror arranged to enable the camera to capture images of the viewer.
5. A tracking system as claimed in claim 4 wherein said mirror is orientated at 135° relative to the axis of the lens of the camera.
6. A tracking system as claimed in any preceding claim wherein the illumination means is moveable in response to movement of the viewer.
7. A tracking system as claimed in any one of claims 1 to 5 wherein the illumination means is fixed.

8. A tracking system as claimed in any preceding claim wherein the illumination means includes a plurality of separate illumination means.
9. A tracking system as claimed in any preceding claim wherein each camera is moveable in response to movement of the viewer.
10. A tracking system as claimed in any one of claims 1 to 8 wherein each camera is fixed.
11. A tracking system as claimed in any preceding claim wherein each camera includes a power zoom function.
12. A tracking system as claimed in any preceding claim wherein the cameras include shutters which are opened as a function of the distance of the viewer from the tracking system.
13. A tracking system as claimed in any preceding claim further including an illumination control means adapted to turn said illumination means on and off.
14. A tracking system as claimed in claim 13 wherein said illumination control means turns said illumination means on and off periodically to thereby create a pulsed source of illumination.
15. A tracking system as claimed in claim 13 wherein said illumination control means monitors said cameras and turns said illumination means on while the shutter of said cameras is open.
16. A tracking system as claimed in any one of claims 13 to 15 wherein the on time for said illumination means is determined as a function of the distance of the viewer from the tracking system.

17. A tracking system as claimed in any one of claims 13 to 16 wherein the illumination control means alters timing of switching of the illumination means on and off in response to changes in the opening and closing of the shutter of the cameras.
18. A tracking tower for locating the eyes of a viewer including:  
an illumination means for illuminating at least the eyes of a viewer;  
a vertically mounted camera for capturing at least the reflected light from the eyes of the viewer; and  
a mirror positioned to enable the vertically mounted camera to capture images in front of the tracking tower.
19. A tracking tower as claimed in claim 18 wherein the illumination means is movable in response to movements of the viewer.
20. A tracking tower as claimed in claim 18 wherein the illumination means is fixed.
21. A tracking tower as claimed in any one of claims 18 to 20 wherein the illumination means includes a bank of infra red LED's.
22. A tracking tower as claimed in any one of claims 18 to 21 wherein the illumination means includes an upper illumination means and a lower illumination means.
23. A tracking tower as claimed in any one of claims 18 to 22 wherein the camera has power pan, tilt, zoom and focus.
24. A tracking tower as claimed in any one of claims 18 to 23 wherein the camera is arranged to pivot about its optical centre.

25. A tracking tower as claimed in any one of claims 18 to 22 wherein the camera is fixed.
26. A tracking tower as claimed in any one of claims 18 to 25 wherein the mirror is oriented at 135° relative to the axis of the lens of the camera.
27. A tracking tower as claimed in any one of claims 18 to 26 wherein the mirror is capable of being reorientated in response to movement of the viewer.
28. A tracking tower as claimed in any one of claims 18 to 27 wherein said camera includes a shutter which is opened as a function of the distance of the viewer from the tracking tower.
29. A tracking tower as claimed in any one of claims 18 to 28 further including an illumination control means adapted to turn said illumination means on and off.
30. A tracking tower as claimed in claim 29 wherein said illumination control means turns said illumination means on and off periodically to thereby create a pulsed source of illumination.
31. A tracking tower as claimed in claim 29 wherein said illumination control means monitors said camera and turns said illumination means on while the shutter of said camera is open.
32. A tracking tower as claimed in any one of claims 29 to 31 wherein the on time for said illumination means is determined as a function of the distance of the viewer from the tracking system.

33. A tracking tower as claimed in any one of claims 29 to 32 wherein the illumination control means alters timing of switching of the illumination means on and off in response to changes in the opening and closing of the shutter of the camera.

34. A system including a plurality of tracking towers as claimed in any one of claims 18 to 33 further including:

a display means for displaying images to be viewed by the viewer, and  
a processing means for receiving images from each camera and processing the images to detect the position of the viewers eyes.

35. A system as claimed in claim 34 wherein the processing means is further adapted to detect at least one further reference point from the received images.

36. A system as claimed in claim 34 wherein the at least one further reference point includes at least one of the forehead, top of the head, side of the head, or glasses of the viewer.

37. A system as claimed in any one of claims 34 to 36 wherein the output from the processing means is fed back to each tracking tower to enable each camera to be adjusted in response to movements of the viewer.

38. A system as claimed in any one of claims 34 to 37 wherein the output from the processing means is fed back to each tracking tower to enable each mirror and/or illumination means to be adjusted in response to movements of the viewer.

39. A system as claimed in any one of claims 34 to 38 wherein at least one tracking tower is located on either side of the display means, and the processing means is located below the display means.

40. An autostereoscopic display device including the system as claimed in any one of claims 34 to 39.

41. A method of tracking the eyes of a viewer including:

projecting light capable of being reflected from the cornea of a viewer from at least one illumination means onto the eyes of the viewer;

capturing the image of the viewer by a plurality of cameras capable of detecting the reflected light from the viewers cornea;

and processing the captured images from each camera in a processing means to determine the position of the viewers eyes.

42. A method of tracking the eyes of the viewer as claimed in claim 41 including:

further processing the captured images to determine at least one further reference point.

43. A method as claimed in claim 42 wherein said further processing includes determining at least one of the forehead, top of the head, side of the head, or glasses of the viewer.

44. A method as claimed in any one of claims 41 to 43 further including:

inputting the output from the processing means into control means for the plurality of cameras and reorientating the position of the plurality of cameras in response to the location of the viewers eyes.

45. A method as claimed in any one of claims 41 to 44 further including:

inputting the output from the processing means into control means for the at least one illumination means and reorientating the position of the at least one illumination means in response to the location of the viewers eyes.

46. A method as claimed in any one of claims 41 to 45 further including:

positioning at least one mirror in the optical path of at least one of said

plurality of cameras to thereby assist the at least one of said plurality of cameras to capture the image of the viewer.

47. A method as claimed in claim 46 further including:

inputting the output from the processing means into control means for the at least one mirror and reorientating the position of the at least one mirror in response to the location of the viewers eyes.

48. A method as claimed in any one of claims 41 to 47 wherein said viewer is wearing glasses and wherein the captured images are firstly processed to determine the position of the glasses of the viewer to thereby assist in locating the eyes of the viewer.

49. A method as claimed in any one of claims 41 to 48 further including adjusting the shutter opening time of the cameras as a function of the distance of the viewer from the tracking system.

50. A method as claimed in any one of claims 41 to 48 further including turning said illumination means on and off.

51. A method as claimed in claim 50 wherein said illumination means is turned on and off periodically to thereby create a pulsed source of illumination.

52. A method as claimed in claim 50 further including monitoring said cameras and turning said illumination means on while the shutter of said cameras are open.

53. A method as claimed in any one of claims 50 to 52 further including adjusting the on time of the illumination means as a function of the distance of the viewer from the illumination means.

54. A method as claimed in any one of claims 50 to 53 further including altering the timing of switching of the illumination means on and off in response to changes in the opening and closing of the shutter of the cameras.
55. A method as claimed in any one of claims 41 to 54 further including comparing the output of the processing stage with previous results to determine whether the determined position for the viewers eyes contain erroneous results.
56. A method as claimed in any one of claims 41 to 55 further including comparing the output of the processing stage with predefined attributes to determine whether the determined position for the viewers eyes contain erroneous results.
57. A method as claimed in any one of claims 42 to 56 wherein said at least one futher reference point is utilised to determine the position of the viewers eyes when said processing stage is unable to locate the viewers eyes.
58. A method as claimed in any one of claims 55 to 57 wherein said at least one futher reference point is utilised to determine the position of the viewers eyes when comparing the output of the processing stage indicates that an erroneous result has occured.
59. A method as claimed in any one of claims 41 to 55 wherein said processing includes utilising a method of triangulation to assist in the location of the viewers eyes.
60. An autostereoscopic display system including:
  - a display means for displaying images to be viewed by a viewer;
  - a tracking tower located on either side of the display means, each tracking tower including:
    - an upper and lower illumination means for illuminating at least the

eyes of a viewer;

a vertically mounted camera for capturing at least the reflected light from the eyes of the viewer; and

a mirror positioned to enable the vertically mounted camera to capture images of the viewer in front of the tracking tower;

a processing means for receiving the images captured by each camera, determining the position of the viewers eyes, and sending the output from the processing means to each tracking tower to thereby adjust each said camera in response to movement of the viewer;

and wherein the output from the processing means is utilised to display respective left and right eye images of the image to be viewed by the viewer on the display means.

61. A display system as claimed in claim 60 wherein said processing means is located below the display means.

62. A display system as claimed in claim 60 or claim 61 wherein output from the processing means is utilised to adjust the orientation of each illumination means in response to movement of the viewer.

63. A display system as claimed in any one of claims 60 to 62 wherein each illumination means includes a bank of infra red LED's.

64. A display system as claimed in any one of claims 60 to 63 wherein output from the processing means is utilised to adjust the orientation of each camera in response to movement of the viewer.

65. A display system as claimed in any one of claims 60 to 64 wherein each camera is arranged to pivot about its optical centre.

66. A display system as claimed in any one of claims 59 to 64 wherein output from the processing means is utilised to adjust the orientation of each mirror in response to movement of the viewer.

67. A display system as claimed in any one of claims 60 to 66 wherein said processing means utilises a method of triangulation to assist in the location of the viewers eyes.

1/9

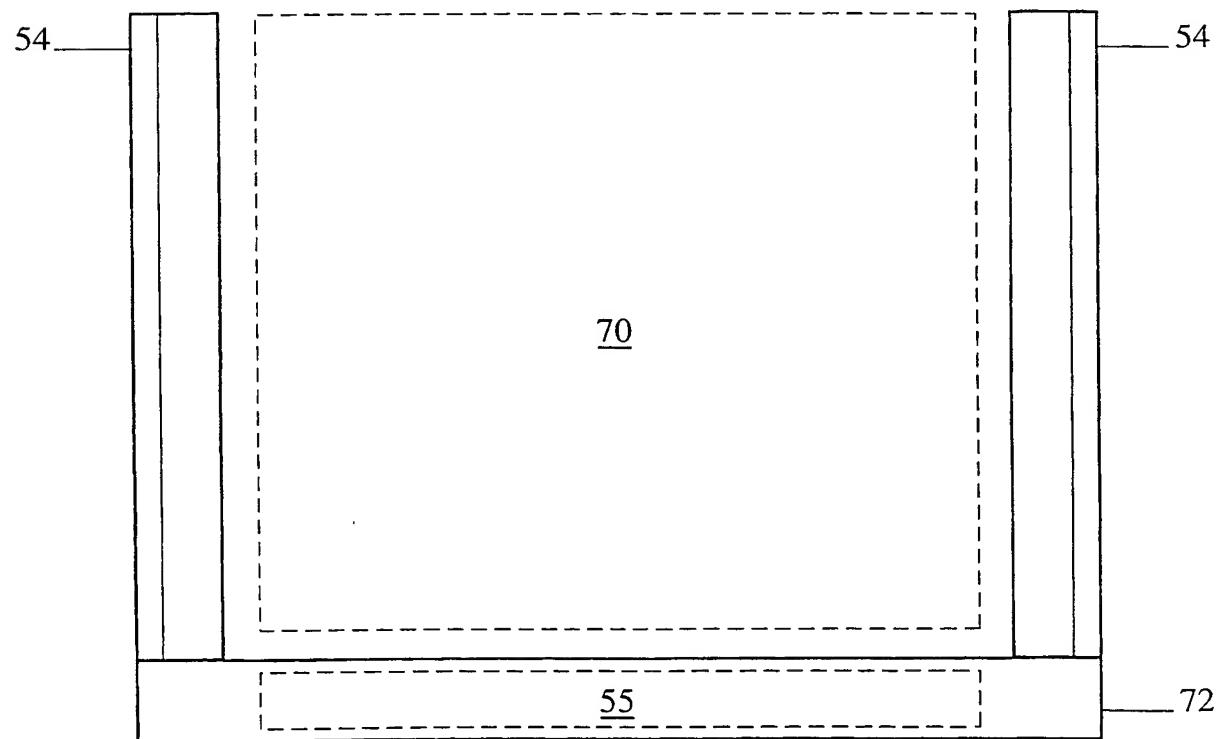
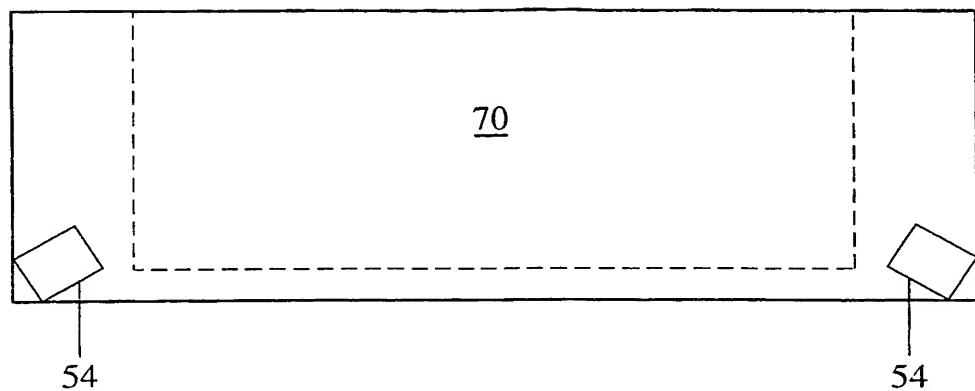


Fig 1.

2/9

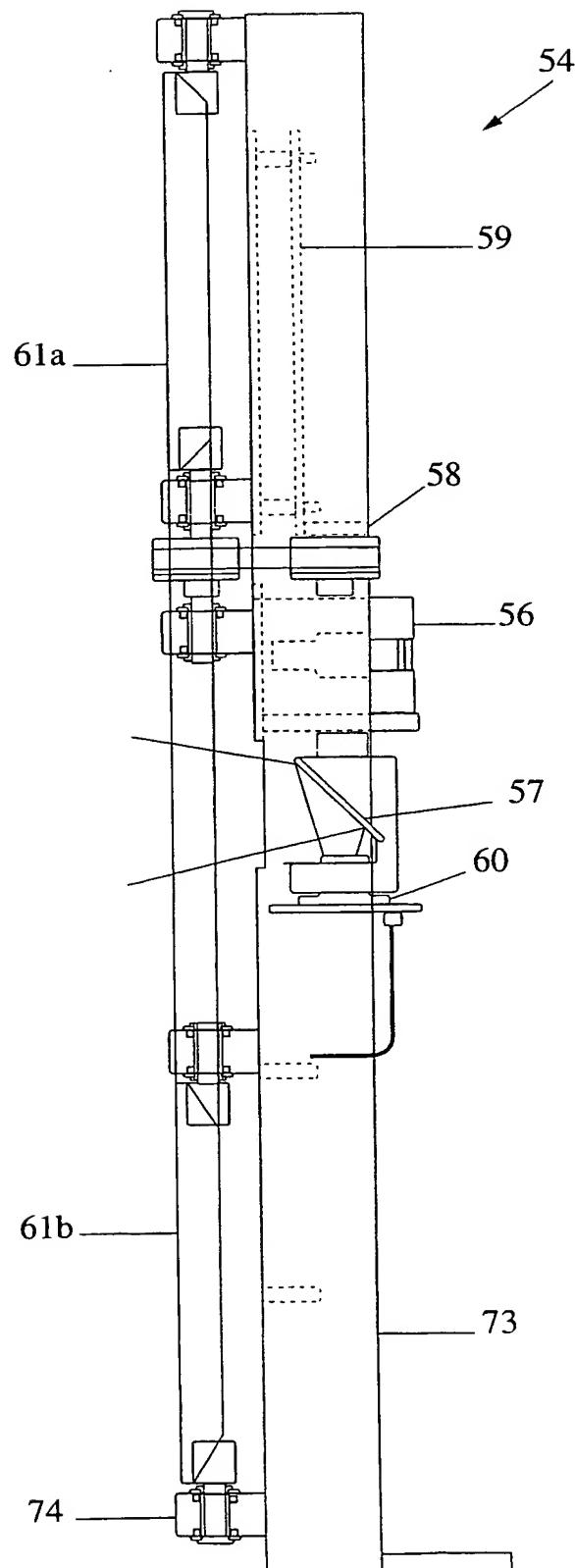


Fig 2.

3/9

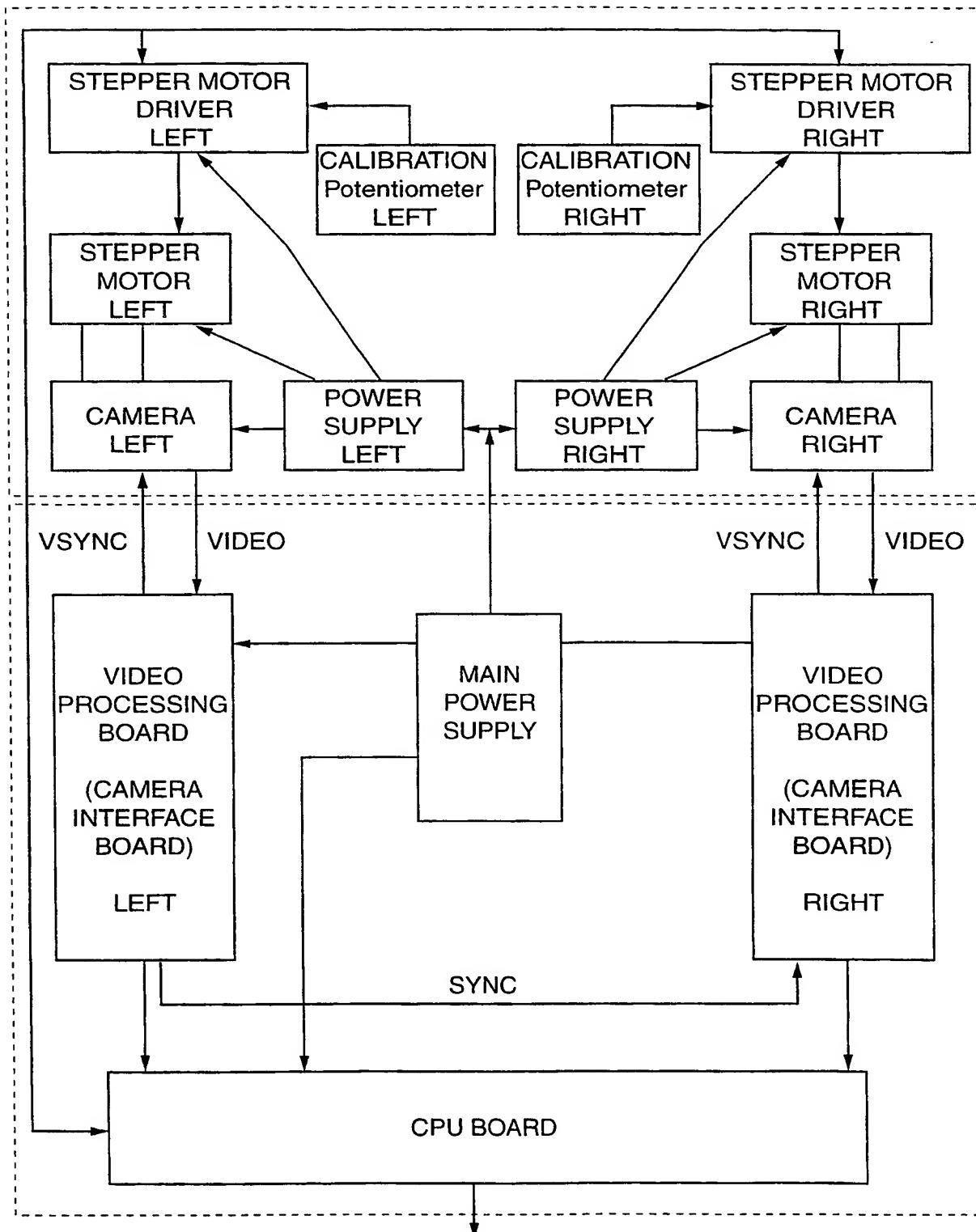


Fig 3.

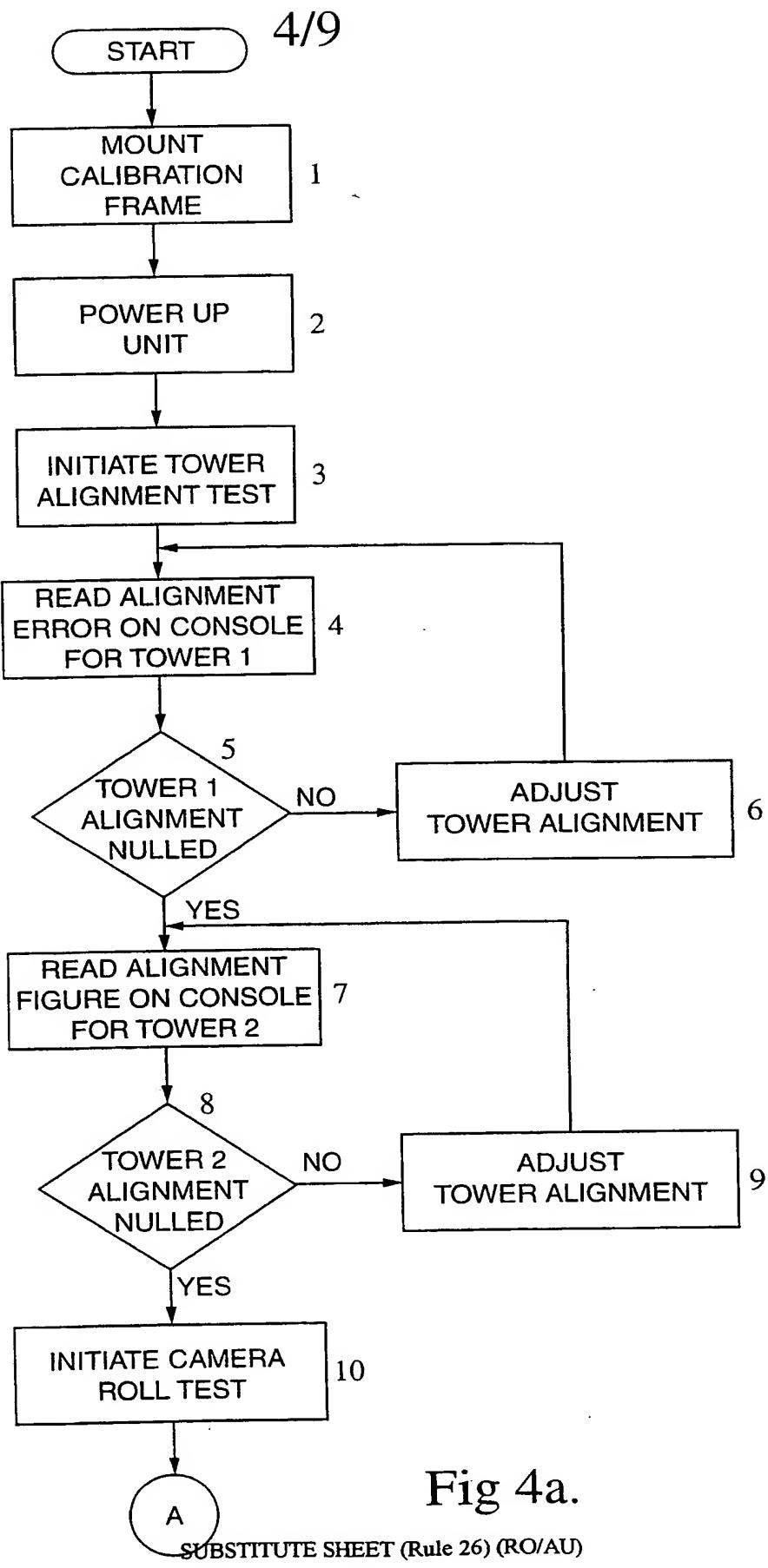
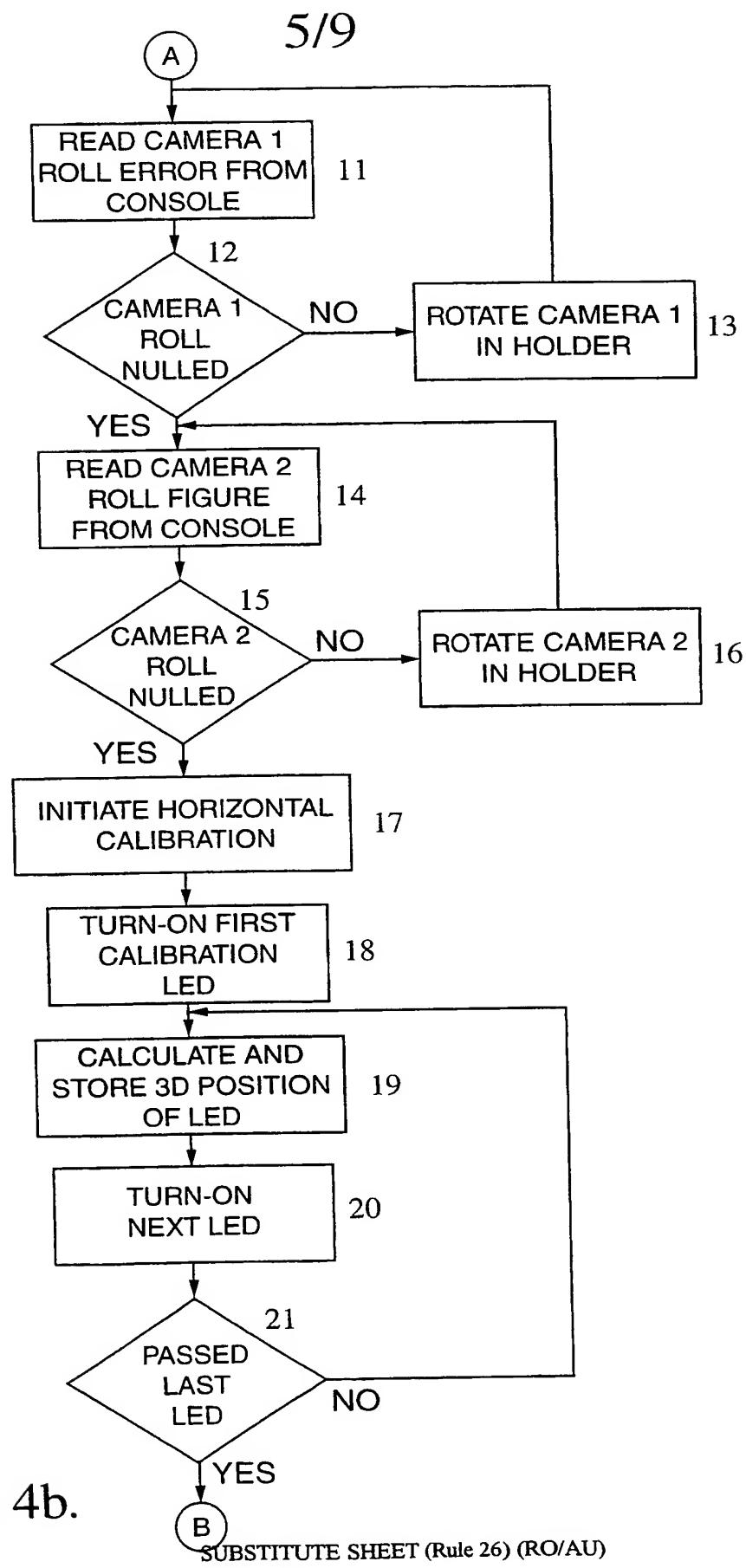


Fig 4a.



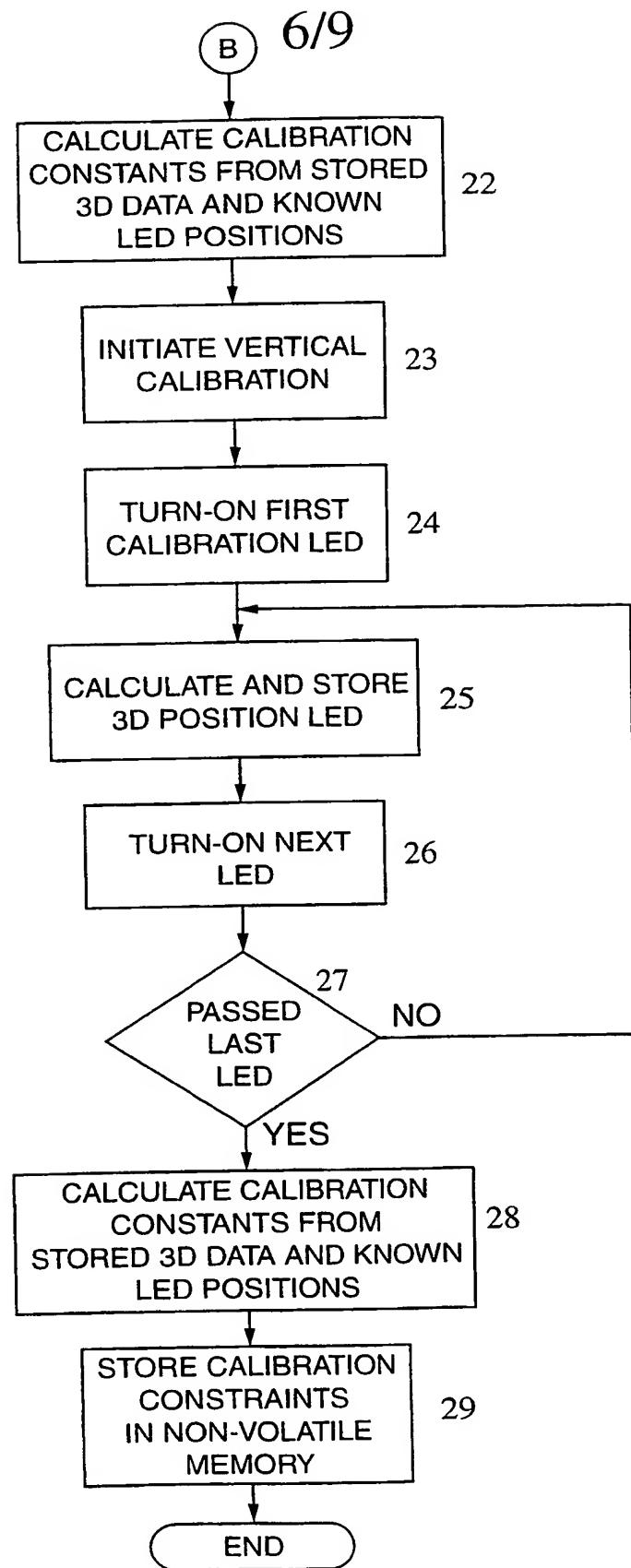


Fig 4c.

7/9

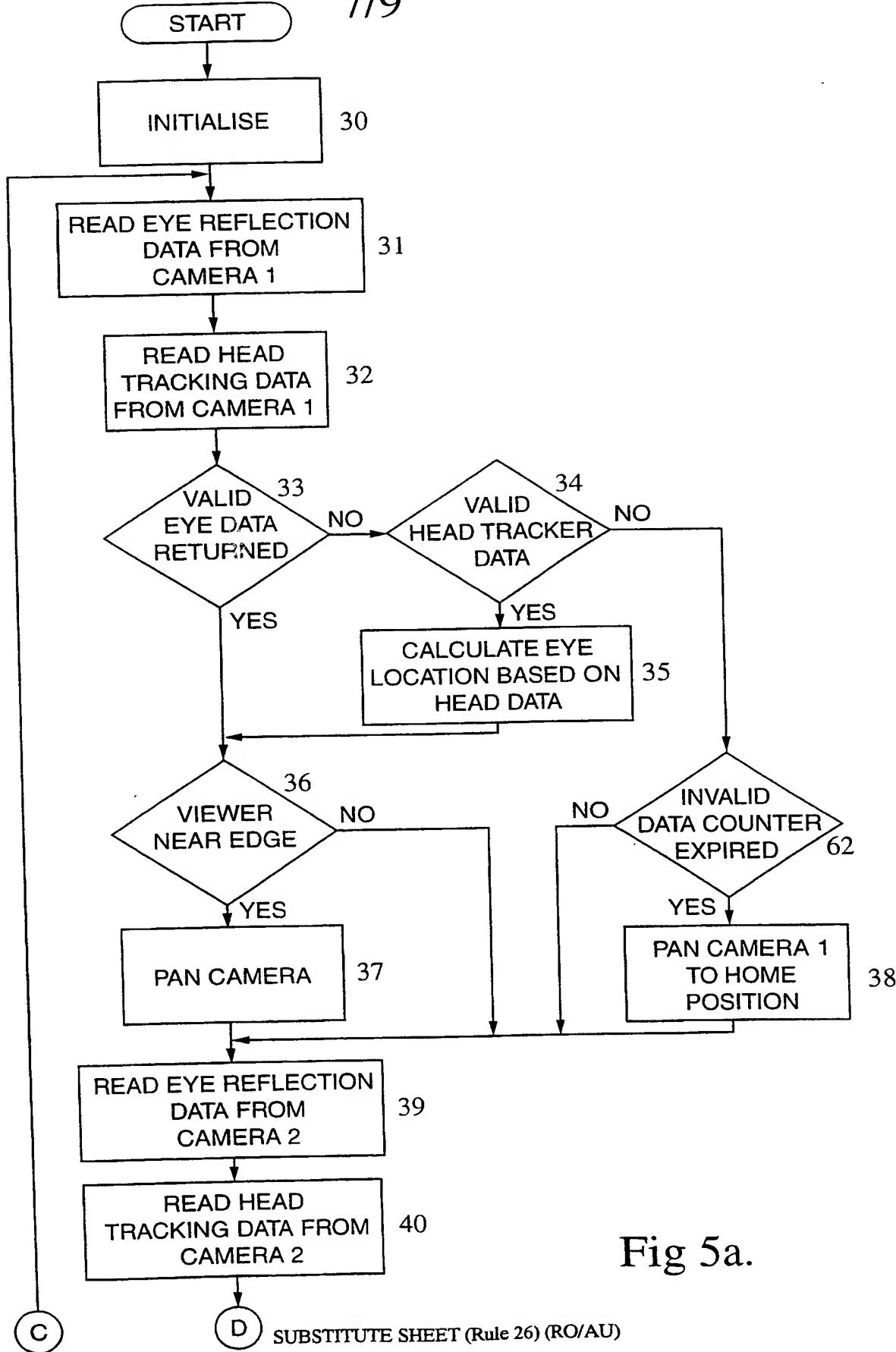


Fig 5a.

8/9

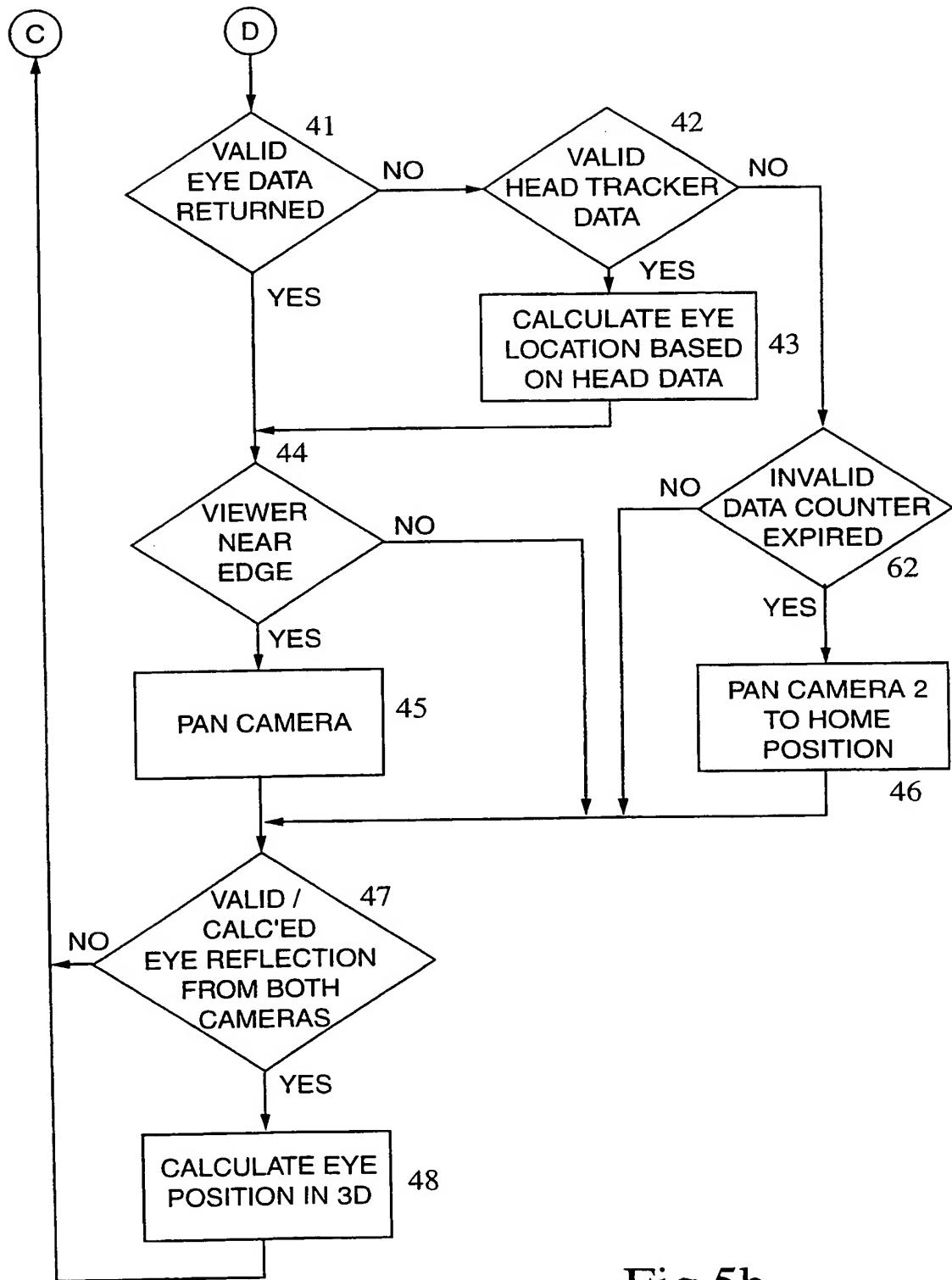


Fig 5b.

9/9

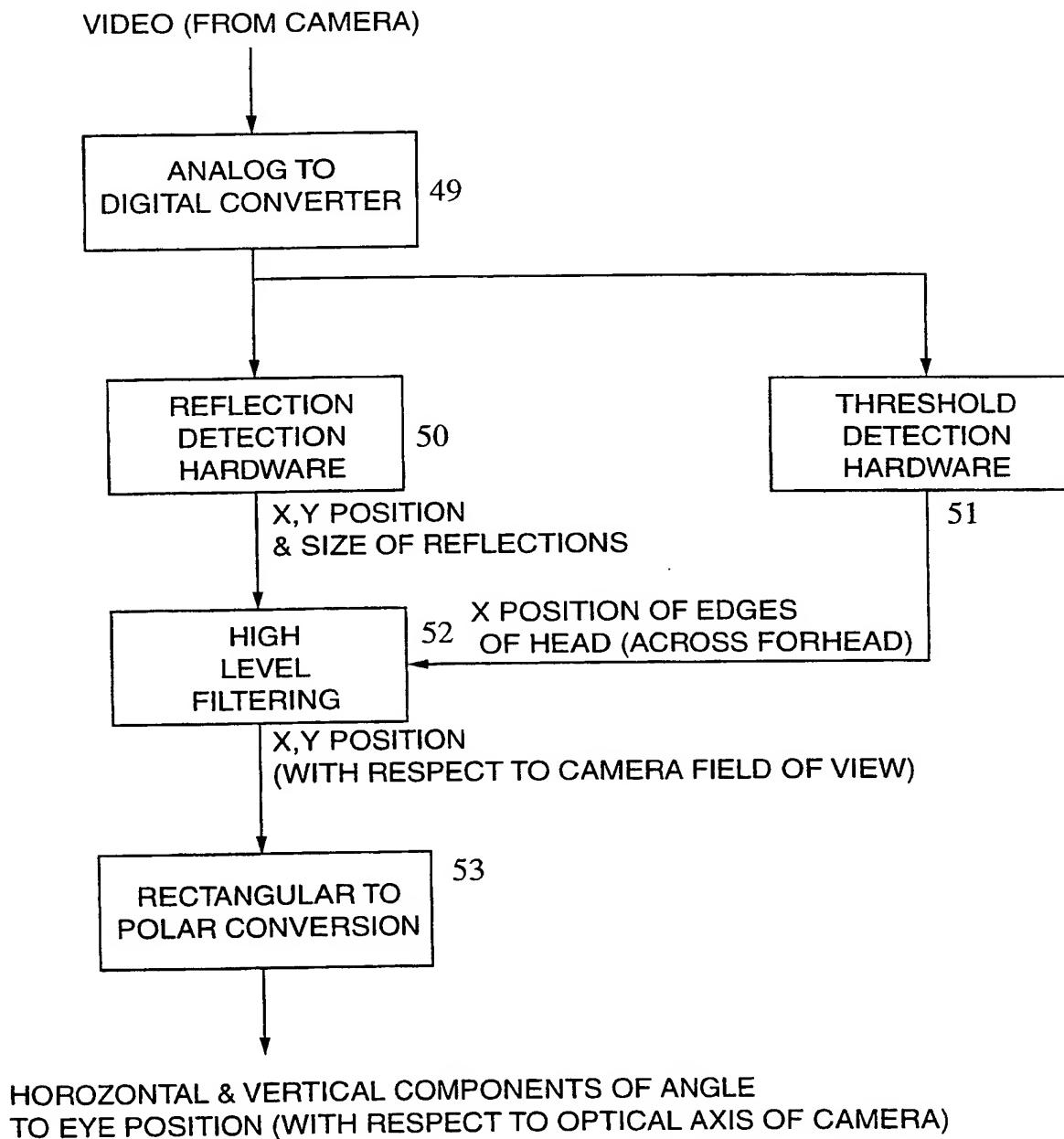


Fig 6.

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/AU 98/00969

## A. CLASSIFICATION OF SUBJECT MATTER

Int Cl<sup>6</sup>: G02B 27/22; H04N 13/04, 15/00; G01B 11/03

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC as above

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPAT + kw (EYEH or VIEWER)(S) (TRACK: OR FOLLOW:) and (camera:)

JPAT as above.

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Patent Abstracts of Japan, P-988, page 38, JP 1-259349 A (NIPPON TELEGR & TELEPH CORP ,<NTT>) 17 October 1989 Abstract	
X	US 5070883 A (KASHARA) 10 December 1991 Column 3 lines 31-54, column 1 lines 48-57	1-17 41-59
A	US 5231674 A (CLEVELAND et al) 27 July 1993 Whole document	

 Further documents are listed in the continuation of Box C See patent family annex

* Special categories of cited documents:		
"A" document defining the general state of the art which is not considered to be of particular relevance	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 19 January 1999	Date of mailing of the international search report 29 JAN 1999
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Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200 WODEN ACT 2606 AUSTRALIA Facsimile No.: (02) 6285 3929	Authorized officer  D.R. LUM Telephone No.: (02) 6283 2544
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**INTERNATIONAL SEARCH REPORT**

International application No.  
PCT/AU 98/00969

**Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1.  Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
  
2.  Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
  
3.  Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

**Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

See attached sheet.

1.  As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims
2.  As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3.  As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
  
4.  No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

**Remark on Protest**

The additional search fees were accompanied by the applicant's protest.  
 No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.  
PCT/AU 98/00969

box II continued

The international application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept. In coming to this conclusion the International Searching Authority has found that there are different inventions as follows:

1. Claims 1-17, and 41-59 are directed to a tracking system which includes a plurality of cameras to capture the reflection of light of each eye and a processing means adapted to process images from each camera so as to detect the position of the viewer's eyes. It is considered that the plurality of cameras comprises a first "special technical feature".
2. Claims 18-40, and 60-67 are directed to a tracking tower which uses a mirror positioned to enable the vertically mounted camera to capture images in front of the tracking tower. It is considered that the mirror comprises a second "special technical feature".

The feature common to all of the claims is a camera for capturing the reflected light from the viewer's eyes. However this common feature is generic in the art. Consequently the common feature does not constitute "a special technical feature" within the meaning of PCT Rule 13.2, second sentence, since it makes no contribution over the prior art. Since there exists no other common feature which can be considered as a special technical feature within the meaning of PCT Rule 13.2, second sentence, no technical relationship within the meaning of PCT Rule 13 between the different inventions can be seen. Consequently it appears that a posteriori, the claims do not satisfy the requirement of unity of invention.

However since all these inventions share the same classification under the IPC they could be searched together without effort which would warrant an additional fee.

**INTERNATIONAL SEARCH REPORT**

International application No. PCT/AU 98/00969
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**C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5365370 A (HUDGINS) 15 November 1994 Whole document	

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

International application No.  
PCT/AU 98/00969

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Document Cited in Search Report	Patent Family Member
US 5070883	JP 2164335

END OF ANNEX

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